Remote Sensing and the Kyoto Protocol: A Review of Available and Future Technology for Monitoring Treaty Compliance

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Abstract- An international workshop was held to address how remote sensing technology could be used to support the environmental monitoring requirements of the Kyoto Protocol. An overview of the issues addressed and the findings of the workshop are discussed.

I. INTRODUCTION

On October 20-22, 1999, two working groups from the International Society of Photogrammetry and Remote Sensing (ISPRS) joined with the University of Michigan to convene a meeting to examine how the remote sensing community can contribute to the information requirements raised by implementation of, and compliance with, the Kyoto Protocol. The meeting originated as a joint effort between the Global Monitoring Working Group and the Radar Applications Working Group in Commission VII of ISPRS. The meeting was attended by representatives from numerous national level government agencies, international organizations and working groups, and academic institutions.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change contains quantified, legally binding commitments to limit or reduce greenhouse gas emissions to 1990 levels and allows carbon emissions to be balanced by carbon sinks represented by vegetation. The issue of using vegetation cover as an emission offset raises a debate about the adequacy of current remote sensing systems and data archives to both assess carbon stocks/sinks at 1990 levels, a decade in the past, and to monitor the current and future global status of those stocks. These concerns and the potential ratification of the Protocol among participating countries is stimulating policy debates and is exposing a need for the exchange of information between the international legal community and the remote sensing community.

While the Kyoto Protocol addresses the global inventory of six greenhouse gases, the attendees focused primarily on CO_2 as it applied to Article 3 (Principles), wherein the importance of sources, sinks, and reservoirs of greenhouse gases is specifically identified. Within this context, the group recognized that Earth observation technologies can help support national accounting and international communication efforts identified in Article 4 (Commitments) and Article 12 (Communication of Information Related to Implementation...) of the protocol.

Some of the key themes addressed by the group were:
1) A review of current and future remote sensing technologies that could be applied to the Kyoto Protocol,
2) The legal implications of transnational remote sensing for treaty verification and compliance assessment, and
3) The approach needed to align the remote sensing community with both the science and policy communities.

The information presented here is only a synopsis of the findings of this group; a larger ISPRS report on the workshop is being prepared for later dissemination.

II. REMOTE SENSING AND TREATY VERIFICATION

A. Legal Implications

One of the first topics addressed was the legal implications of using remote sensing technology in the framework of international treaties. According to international law, there is a clear distinction between airborne remote sensing activities and space-borne activities. Airspace laws require that airborne approaches have the consent of the state being surveyed. This is not the case for space-borne activities, and even active sensors - such as SAR and LIDAR - do not count as infringements on national sovereignty if operated from orbit. Thus, verification of compliance of the Kyoto Protocol could, in effect, be performed by a state, for areas outside its own borders.

However, the *UN Principles Relating to Remote Sensing of the Earth from Outer Space* - which is a non-binding document - states that "as soon as primary and processed data concerning the territory under its jurisdiction are produced, the sensed state shall also have access to them on a non-discriminatory basis and on reasonable cost terms" (principle XII). Hence, if a survey is performed from outer

space, states can legally collect data useful for purposes of the Kyoto Protocol, but data may be subject to certain restrictions on distribution.

It is not clear, however, whether any data collected can be used to compel a state to comply with the protocol since the states have not expressly agreed to permit verification.

B. Applying Remote Sensing to the Kyoto Protocol

The group identified three areas where remote sensing technology could be applied toward facilitating treaty compliance:

1) The development of land cover thematic maps that identify sinks and reservoirs, including the detection and quantification of Afforestation, Reforestation, and Deforestation (ARD) events.
2) The development of remote sensing techniques that directly address a full carbon accounting approach such as the measurement of biomass.
3) The formulation of a 1990 baseline data base of relevant land covers.

However, the group also recognized that the credibility and international acceptance of any proposed remote sensing methodology is essential. To this end, any recommendations should take into account the on-going work of the terrestrial carbon initiative of the IGOS partnership, the IPCC, and other international science programs and entities (e.g., IGBP, IHDP, WCRP, IUFRO, IIASA, etc.). Dialogue with these groups and other national and international entities, such as the World Bank, GEF and national development agencies, will be essential for steering the application of the technology and for capacity building and technology transfer.

III. OVERVIEW OF REMOTE SENSING TECHNOLOGY CAPABILITIES

The group reviewed a large number of remote sensing resources and categorized them according to how they might best be applied to the Kyoto Protocol using the application themes described above. The primary emphasis was on satellite-based technologies, although some aircraft-platform based sensors were also discussed. The groups of instruments were roughly divided into three categories: 1) Passive panchromatic/multi-spectral (including fine and coarse resolution), 2) Active microwave systems (i.e., Radar), and 3) Laser Infrared Detection and Ranging instruments (LIDAR). A listing follows.

Panchromatic/Multi-spectral - Fine Resolution
The spatial resolution ranges between 1 and 250 metres.
Temporal re-visit time ~ 14-46 days.

Landsat TM, ETM+ and MSS, USA, 1972 - present
SPOT HRV, France/Sweden/Belgium, 1986 - present
JERS-1 OPS, Japan, 1992 - 1998
IRS PAN, LISS and WiFS, India, 1995 - present
ADEOS AVNIR, Japan, 1996 - 1997
CBERS CCD and IR-MSS, Brazil/China, 1999 - present
IKONOS, USA, 1999 - present.
EOS-Terra, MODIS, ASTER, MISR, USA/Japan, 1999 - present
EO-1 ALI and Hyperion, USA, Future c.a. 2000
ALOS AVNIR-2 and PRISM, Japan, planned launch 2002

Panchromatic/Multi-spectral - Coarse Resolution
The spatial resolution ranges between 250 meters and 1 km.
Temporal re-visit time daily - weekly.

NOAA AVHRR, USA, 1970's - present
SPOT VEGETATION, France/EU/Sweden/Belgium, 1998 - present
ADEOS OCTS, Japan, 1996 - 1997
CBERS WFI, Brazil/China, 1999 - present
EOS-Terra, MODIS, USA, 1999 - present
ADEOS-II GLI, Japan, planned launch 2000
ENVISAT MERIS, Europe, planned launch 2000

Satellite-based Radar Imaging Systems
Various Resolutions 10-100m

SEASAT (L-band single pol.), USA, 1976
SIR-A;B;C (L-HH; L-HH; X,L,C) USA,1981;1984; 1994
Almaz (S-band), Russia, 1991
ERS AMI (C-band VV pol.), Europe, 1991 - present
JERS SAR (L-band single pol.), Japan, 1992 - 1998
Radarsat-1 (C-band HH pol.), Canada, 1995- present
ENVISAT ASAR (L-band polarimetric), Europe, planned launch 2000
ALOS PALSAR (L-band polarimetric), Japan, planned launch 2002

LIDAR

Vegetation Canopy LIDAR (VCL), USA, planned for launch in mid -2000.
VCL is an active infrared laser which will make soundings of the vegetation canopy providing a vertical distribution profile of vegetation.
The VCL instrument will sample the Earth in 25 m footprints along five parallel transects spaced 2 km apart. Height accuracy is < 1m. Global coverage may be achieved during the 18 months' mission life of the VCL, although clouds still constitute a data acquisition issue.

A. Thematic Mapping and Detection of ARD

Multi-spectral and Panchromatic Systems. Both thematic mapping of land cover and the detection and quantification (to a degree) of ARD events are generally feasible with current multi-spectral systems. Sensors with mid-infrared bands are particularly well suited for thematic mapping of land cover and ARD applications, while panchromatic systems are best limited to ARD applications. Global coverage using these systems is possible, but cloud cover

does pose some limitation to obtaining homogeneous temporal coverage at regional scales, particularly in tropical areas.

While the literature is full of applications results which address general mapping and ARD issues using multi-spectral and panchromatic sensors, the results tend to be site-specific and focused on a particular science objective. The feasibility of identifying those thematic classes directly applicable to the Kyoto Protocol, as defined by the IPCC needs to be investigated.

Active Microwave Sensors. The generation of thematic maps and the detection of ARD events using current satellite-based radar imaging systems have proven to be problematic. Good thematic mapping is difficult without polarimetric and/or multi-frequency data. Some ARD events such as clearcutting and massive burning can be detected using the single band monopol. systems. In those cases, the all-weather capability of radar systems does present a potential advantage over other systems and should not be overlooked. Multi-band/polarimetric and interferometric-capable radar systems are currently available on aircraft platforms (e.g., NASA's AIRSAR) and could be used for smaller area applications. Also, two L-band polarimetric radar imaging systems are being planned for future satellite missions. NASDA's PALSAR and ESA's ASAR could prove valuable for detecting ARD events globally during all seasons (Kellendorfer et al. 1998).

LIDAR. The use of LIDAR systems to make thematic maps and to detect ARD events is still unproven. The NASA VCL does not take images; it takes a series of samples. This will make the production of thematic products time consuming and difficult. However, the ability to repeatedly characterize structural attributes at specific locations or to collect sample sets in known ARD areas could prove extraordinarily useful (Blair et al. 1999).

B. Quantifying Changes in Biomass Stocks

Multi-spectral Systems. Direct measurements of total above-ground forest biomass stocks or of changes in such is not currently feasible with (passive) optical systems. However, indirect estimations of biomass change, are possible, to a limited extent, by using forest growth models and PAR parameters (photosynthetically active radiation), which can be derived from remotely sensed data. The combination of environmental data, models, and PAR parameters is currently used to predict NPP (net primary production) which is presented in terms of units of carbon (e.g., KgC/Ha/Yr. See Asrar et al. 1984, Tucker and Sellers 1986, Prince et al. 1995).

It is also possible to detect thinning, selective logging, and biomass burning events using multi-spectral sensors. Even a simple identification that these events have taken place over time is a valid contribution in the context of the protocol (Justice et al. 1996).

Active Microwave sensors. The application of radar systems to measure and detect changes in biomass is an active area of research and development. However, the working group generally agreed that the currently available radar satellite systems are not well suited for biomass estimation. Longer wavelengths and/or polarization and interferometric modes are needed to push the biomass saturation levels forward and to improve accuracy (Dobson et al. 1992, Imhoff 1995). Single channel C-band systems have very limited application; however, L-band data may be useful for very coarse biomass estimates especially as concerns ARD events such as regrowth etc. Again, as mentioned in the previous section, future space-based polarimetric radar systems are in the planning stage and may prove useful for this application in the near future.

Aircraft-based radar sensors having full multi-band, polarimetric, and interferometric capabilities (such as NASA's JPL/AIRSAR and others) currently exist and have proven capable of detecting biomass in a wide range of forests up to 200 tons/ha dry above ground biomass (Ranson et al. 1997). Furthermore, low frequency aircraft-based sensors such as Sweden's CARABAS (Ulander et al. 1998) and NASA's BioSAR (Imhoff et al. 2000) have also recently shown that biomass measures can be accurately derived well above 200 tons/ha. These systems show great promise for local applications. However, placing these systems on-orbit is still problematic, and it is uncertain if they will ever be available on space-based platforms.

LIDAR. Combined with allometric data, the data collected by VCL should be capable of providing accurate measures of above ground biomass from the vegetation structure and canopy height measures. Combined with spatially extensive data, such as optical or SAR imagery, interpolation of biomass estimates between VCL sample points can be used to provide local-regional biomass estimates. As mentioned previously, it remains to be seen how these data will be applied over large areas, but they will certainly be useful for specific sites.

C. Provision of a 1990 forest baseline data set.

Since this requirement of the Kyoto Protocol is driven by a firm temporal requirement, our choices are limited to those systems that were available during the period in question.

Multi-spectral Sensors. The use of fine or high resolution data such as Landsat TM or SPOT for compiling a continental scale or global 1990 baseline is possible - though expensive. It is certainly feasible at a national level for smaller countries or regions. Archives of Landsat TM and MSS and SPOT HRV exist and could be used for this purpose.

The use of coarse resolution data is generally feasible, although spatial resolution issues for many areas would limit their utility. However, a Global Land Cover map from 1992 has been generated from NOAA AVHRR data within IGBP DIS, and archives of NOAA AVHRR data exist for the required time (Townsend et al. 1994, Estes et al. 1999).

Active Microwave Systems. The working group's assessment was that it is not feasible to develop a useful 1990 baseline using SAR data. However, 100 m resolution JERS-1 mosaics exist over the Earth's tropical belt from 1995-1996 and mosaics covering the Earth's boreal belt are under generation. These data could be used to begin a mid-1990's baseline.

LIDAR. Not feasible. No data available.

IV. CONCLUSIONS

There are a variety of remote sensing tools available to address the needs of the Kyoto Protocol. However, there is still a lack of connection between the techniques and approaches that have been developed and the specific measurement requirements of the protocol. In the short term, the remote sensing community should strive to demonstrate techniques that meet IPCC guidelines for ARD monitoring and detection, using as many of the available remote sensing technologies as possible. In addition, it was generally agreed that the remote sensing community could help move the policy community toward a total carbon accounting perspective to the protocol. To this end the remote sensing community should strive to characterize the potential of current systems to accurately measure biomass across a wide spectrum of cover types and develop new systems where needed to accomplish this.

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ACRONYMS

ARD - Afforestation, Reforestation and Deforestation
GEF - Global Environment Facility
IGBP - International Geosphere Biosphere Programme
IHDP - International Human Dimensions of Global Change
IIASA - International Institute for Applied Systems Analysis
IPCC - Intergovernmental Panel on Climate Change
ISPRS - International Society for Photogrammetry and Remote Sensing
IUFRO - International Union of Forest Research Organizations
WCRP - World Climate Research Programme

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